Exhibit G

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The Regulatory and Mineralogical Definitions of Asbestos and Their Impact on Amphibole Dust Analysis

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Although a familiar occupational health topic, the term *asbestos* generally is not well understood. Significant differences between mineralogical and regulatory delinitions sustain the confusion. Definitional ambiguity is addressed and its effect upon the characterization of New York State tremolitic talc are investigated. Analysis of asbestiform and nonasbestiform airborne dust populations clearly demonstrates the nonspecificity of the regulatory definition and the 3:1 aspect ratio "fiber" counting scheme. Shifting to a higher aspect ratio would reduce false positives radically without a loss in sensitivity for true asbestos. Any change in aspect ratio, however, must be accompanied by a mineralogically correct definition of asbestos if proper mineral characterization is to be assured.

Introduction

Few environmental health hazards have been as widely publicized or viewed with as much dread as asbestos. Despite this attention, considerable confusion exists as to what the generic term ***asbestos*** actually means. American regulatory definitions are incomplete and, in some instances, at odds with the mineralogical view of this substance. The purpose of this paper is to review this definitional problem and demonstrate its effect on one controversial dust environment.

Definitions

Regulatory

The National Institute for Occupational Safety and Health **(NIOSH)** has established the definitions and analysis methods for asbestos used by almost all regulatory bodies in the United States. Under this scheme, asbestos is defined as any fiber **of** chrysotile, crocidolite. amosite, anthophyllite, tremolite or actinolite. A ***fiber*** is defined as a particle with a length to width ratio (aspect ratio) of at least 3:1 and a length **of** 5 μm or more as determined by the phase-contrast optical microscope **(PCM)** at a magnification of **450X** to 500X.[1] While NIOSH acknowledges that this dimensional criteria and fiber counting method is not specific to asbestos,[2] regulatory definitions offer no further description of what is or is not asbestos.

Mineralogical

In the ***Glossary of Geology,*** asbestos is defined simply as

> **A** commercial term applied to a group of highly fibrous silicate minerals that readily separate into long, thin, strong fibers of sufficient flexibility to be woven, are heat resistant and chemically inert, and possess a high electrical insulation and therefore are suitable for uses where incombustible, nonconductive or chemically resistant material is required.[3]

While chemical and electrical inertness are properties shared by almost all silicates. asbestos is unique because of its long, thin, strong, flexible fibers. Accordingly, to a mineral scientist the term ***asbestos*** always includes some reference to the fibrous crystal growth pattern often described as the "asbestiform habit." Mineralogically, asbestos is a matter of how a mineral grows, not simply a matter of one mineral versus another or an arbitrary dimensional concept.

Several minerals? including those designated in United States' regulations, do grow in nature in an asbestiform habit. These. would include the most commonly exploited forms **of** asbestos: chrysotile, crocidolite, and amosite. The regulated asbestiform minerals, however, also occur in nature in a nonasbestiform habit. In all cases, the nonasbestiform habit is by far the more common. Table I lists the asbestiform and nonasbestiform habits of the six regulated minerals and their separate Chemical Abstract Service numbers. The list conforms to the nomenclature set forth by the United States Department of the Interior.[4]

It should be noted that the chemical composition is the same for each mineral in either growth habit. In **all** cases except chrysotile, the internal crystal structure is identical as well. **Also,** the first three minerals have been assigned separate names to distinguish the different growth patterns, while the last three—anthophyllite, tremolite, and actinolite— have not. For these three the nonasbestiform analogs are common rock-forming minerals found throughout the earth's crust and, therefore, routinely encountered in many industries. Figure I graphically depicts the basic difference in the two mineral growth patterns while Figure **2** contrasts the **two** macroscopically and microscopically.

While nonasbestiform particles clearly differ from asbestiform particles, many would be counted as asbestos under the current regulatory 3:I dimensional criterion for a fiber when an ore is crushed, milled or otherwise reduced. Thus, while all asbestos is fibrous. not all fibers are asbestos. It is also important to note that asbestiform fibers cannot be created from nonasbestiform materials by crushing. milling, or grinding. Mineralogically. a particle with an aspect ratio of 3:1 would not be considered a fiber. Because the term *fiber* is interpreted indifferent ways. tis use in this paper will be restricted

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TABLE I
Asbestiform and Nonasbestiform Varieties of Selected Silicate Minerals and Their Chemical Abstract Service Numbers (CAS)

Asbestiform Variety (CAS #)	Chemical Composition	Nonasbestiform Variety (CAS #)
Serpentine Group:		
Chrysotile (12001-29-5)	$Mg_3(Si_2O_5)(OH)_4$	antigorite. lizardite (12135-86-3)
Amphibole Group:		
Crocidolite (12001-28-4)	$Na_2Fe_3Fe_2(Si_8O_{22})(OH,F)_2$	riebeckite (17787-87-0)
Grunerite asbestos (amosite) (12172-73-5*)^A	$(Mg,Fe)_7(Si_8O_{22})(OH,F)_2$	cummingtonite-grunerite (14567-61-4)
Anthophyllite asbestos (77536-67-5*)	$(Mg,Fe)_7(Si_8O_{22})(OH,F)_2$	anthophyllite (17068-78-9)
Tremolite asbestos (77536-68-6*)	$Ca_2Mg_5(Si_8O_{22})(OH,F_2)$	tremolite (14567-73-8)
Actinolite asbestos (77536-66-4*)	$Ca_2(Mg,Fe)_5(Si_8O_{22})(OH,F)_2$	actinolite (13768-00-8)

^AThe presence of an asterisk following a CAS Registry Number indicates that the registration is for a substance which CAS does not treat in its regular CA index processing as a unique chemical entity. Typically, this occurs when the material is one of variable composition: a biological organism, a botanical entity, an oil or extract of plant or animal origin. or a material that includes some description of physical specificity. such as morphology.

in the interest of clarity to specific definitions only. To reflect the mineralogical characteristics of asbestos in a definition, a group of mineral scientists agreed to the following?'

A. Asbestos — A collective mineralogical term that describes certain silicates belonging to the serpentine and amphibole mineral groups, which have crystallized in the asbestiform habit causing them to be easily separated into long, thin, flexible, strong fibers when crushed or processed. Included in the definition are chrysotile; crocidolite. asbestiform grunerite (amosite); anthophyllite asbestos; tremolite asbestos; and actinolite asbestos.

B. Asbestos Fibers — Asbestiform mineral fiber populations generally have the following characteristics when viewed by light microscopy:

1. Many particles with aspect ratios ranging from 20:1 to 100:1 or higher (>5 μm length)
2. Very thin fibrils generally less than 0.5 μm in width, and
3. In addition to the mandatory fibrillar crystal growth, two or more of the following attributes:
   (a) Parallel fibers occurring in bundles;
   (b) Fibers displaying splayed ends;
   (c) Matted masses of individual fibers; and
   (d) Fibers showing curvature[5]

Many of those who contributed to this definition and support the listed criteria have published extensively on the problems associated with the NIOSH definitions and the membrane filter method.[4,6-17] This definition has been incorporated in a proposed American Society for Testing and Materials (ASTM) method submitted to committee D-22.05 (January 14. 1988). The criteria have long been endorsed by the U.S. Department of the Interior.[4,11,13]

While all mineral scientists may not agree with every entry in this definition, it does present a more mineralogically accurate description of asbestos and asbestos fibers than does the regulatory definition. This is especially true when it is applied to a dust population rather than on a particle by particle basis. The definition, therefore, will be used in the remainder of this paper as the "mineralogical" definition of asbestos. It might be noted that the width criterion (0.5 μm) represents a dimension below which all individual "fibrils" and clumps or masses of fibrils would be encountered in processed asbestos. Unprocessed clumps or masses may exceed this width, but such particles would not be representative of common airborne asbestos fibers.

The Study Environment

One of the most controversial workplace exposures associated with this definitional issue involves the mining and milling of New York State tremolitic talc. Accordingly, a study was undertaken to contrast dust data obtained in this environment with both the regulatory and mineralogical definitions discussed above.

New York State tremolitic talc is an industrial grade talc used extensively in the ceramics. tile, and paint industries. Since 1974 the R.T. Vanderbilt Company. Inc., has owned and operated the only New York State tremolitic talc mine.

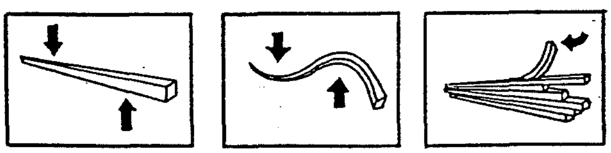
Talc mined from this operation varies somewhat in mineral content but an assay of the ore generally reflects 40%–60% tremolite. 1%–10% anthophyllite, 20%–40% talc. 20%–30% serpentine (antigorite-lizardite). and 0%–2% quartz.('''

The R.T. Vanderbilt Company states that all of the tremolite and anthophyllite in its talc products appear only in the nonasbestiform habit.[19,20] In 1980. however, **NIOSH** published a technical report entitled Occupational ***Exposure to Talc*** Containing Asbestos'''' specifically addressing this mineral dust exposure. In the report, **NIOSH** applied its regulatory asbestos definition to bulk and airborne dust -samples collected at this mine and reported over 70% asbestos for airborne fibers satisfying the **3:1 or** greater aspect ratio and greater than 5-pm length limit (NIOSH PCM method). Particles were identified as tremolite and anthophyllite **by** standard X-ray diffraction technique.

Method of Study

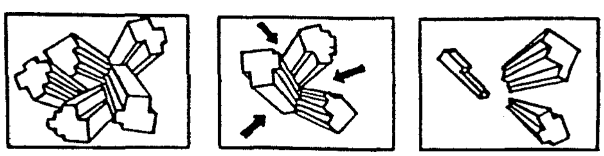
Samples for particulate analysis were collected on open-faced. 37-mm diameter Millipore type AA filters (0.8-μm pore size, Millipore Corp., Bedford, Mass.). Precalibrated Mine Safety Appliances' Model ***G*** pumps were used to draw air through these filters at a rate of 1.7 L/min. Although **fiber** sampling technique has changed since, this technique was used in order to compare results with data previously collected. Filters were changed throughout a full work shift

ASBESTIFORM



In the asbestiform habit, mineral crystals grow in a single dimension, in a straight line until they form long, thread-like fibers with aspect ratios of 20:1 to 1000:1 **and** higher. When pressure is applied, the fibers do not shatter but simply bend much like a wire. Fibrils **of** a smaller diameter are produced as bundles of fibers are pulled apart. This bundling effect is referred to as polyfilamentous.

NONASBESTIFORM



In the nonasbestiform variety, crystal growth is random, forming multidimensional prismatic patterns. When pressure is applied, the crystal fractures easily, fragmenting into prismatic particles. Some of the particles or cleavage fragments are acicular or needle-shaped **as a** result **of** the tendency of amphibole minerals to cleave along two dimensions but not along the third. Stair-step cleavage along the edges of some particles is common, and oblique extinction is exhibited under the microscope. Cleavage fragments never show curvature.

Figure 1—Asbestiform and nonasbestiform graphics

as needed to prevent overloading. In all, 22 air samples were obtained representing nine work activities in the R.T. Vanderbilt Co.. Gouverneur, **New York. mine** and mill. Work activities sampled included milling (Hardinge and Wheeler mills), drying. packing, bag stacking, crushing, mine drilling, scraping, and tramming.

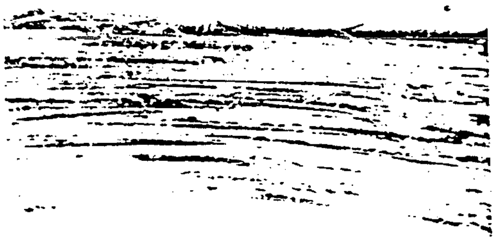
Analyses were performed by The **R.J.** Lee Group, Inc., of Monroeville. Pennsylvania (Project No. 86-12318). Analytical techniques employed included phase contrast microscopy (PCM), polarized light microscopy (PLM). scanning electron microscopy (SEM), computer-controlled scanning electron microscopy (CCSEM), and transmission electron microscopy (TEM). In accordance with **NIOSH** method 7400, all samples received PCM particle counts at **400X** magnification in Walton-Beckett graticule measuring at least 5-μm long with a 3:1 or greater aspect ratio. Beyond these specified parameters, exact particle widths and lengths were not measured. For each sample, 100 fields or 100 particles, whichever came first, were counted (with a minimum of 20 fields). In all, 2295 particles were counted and sized by PCM.

A separate wedge was cut from each filter for PLM analysis. Particles were tapped, then gently scraped from the wedge to a glass slide. Any remaining particles were captured by rolling a needle moistened with 1.592 refractive index (RI) liquid over the surface of the filter wedge (RI selected for low-iron talc). Additional 1.592 RI liquid was added to the slide and used to wash particles from the needle onto the slide. It should be noted that this transfer technique could bias the PCM analysis if very fine particles were lost in the transfer. Additional analysis of particles not removed from the filter (another filter section) suggests such bias is unlikely for tremolite (see SEM particle width discussion below). PLM counts were made in a 1.592 RI oil to differentiate talc from all amphiboles on all 22 air samples. Following this basic cut, tremolite was differentiated from anthophyllite by angle of extinction (tremolite has an inclined extinction **of** 14° to 17°, while anthophyllite exhibits parallel extinction). Since all asbestos exhibits parallel extinction, mineral habit (asbestiform or nonasbestiform) then was decided on the basis of criteria noted in the mineralogical definition. Depending on particle concentration for each of the 22 samples, 100 to 200 points were counted and characterized at 100X magnification, yielding a minimum of 2200 particles subjected to PLM analysis. If positive particle identification could not be made at 100X total magnification. higher magnifications (up to 400X) were applied on a particle by particle basis. As in the PCM analysis, only particles with an aspect ratio of 3:1 or greater and a length of 5 μm or more were so characterized. Although exact length and width measurements were not obtained, particles were sized by basic aspect ratio categories (*i.e.*, those 3:1 or greater, 10:1 or greater, *etc.*). One additional step was taken in the PLM analysis in which particles presumed to be anthophyllite (> 1.592 RI) were tested for "transitional" phases (meaning talc intertwined with or evolving from anthophyllite and/or biopyriboles). This was accomplished by finding particles which most closely appro-:mated the same si: . ind morphological characteristics of these suspect particles on another portion

EXAMPLES

Amphiboles with
Separate Names:

RAW ORE



amosite

cummingtonite-grunerite

Amphiboles with
the Same Name:

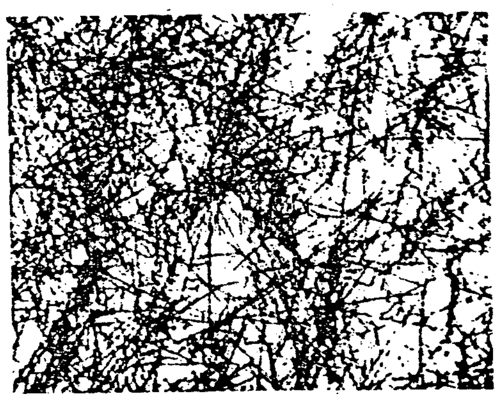
tremolite

tremolite

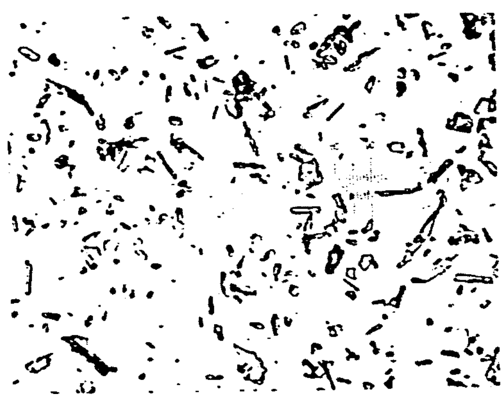
ASBESTIFORM NONASBESTIFORM

EXAMPLES

Amphiboles with
Separate Names:



arnosite



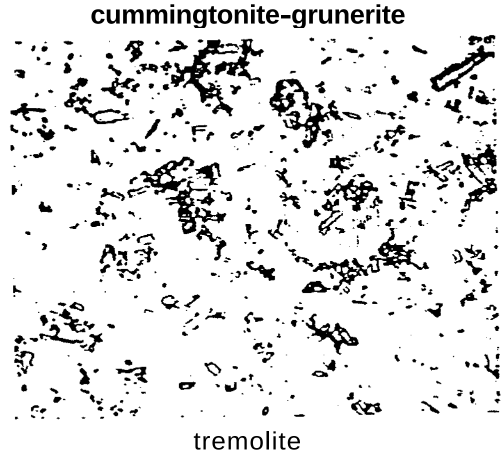
cummingtonite-grunerite

MICROSCOPIC

265X Magnification,
2.75 μm/Division

Amphiboles with
the Same Name:

tremolite



tremolite

of the filter and testing them at 1.608 RI (the low gamma index lor anthophyllite). Because of problems inherent in this technique. testing the same particle with different RI liquids was not possible. Particles with an index of refraction between 1.592 and 1.608 were classed as "transitional." In all, 6 samples underwent this additional analysis.

To test further the differences and similarities between asbestiform dust populations and the tremolitic talc dust environment. electron microscopy was employed on 5 samples most representative of common mine and mill exposures(*e.g.*, product packaging). SEM with energy dispersive X-ray (EDX) first required the mounting of another 1/8 filter wedge from each sample on a carbon-coated stub. Fifty fields at 2000X magnification then were analyzed for count, size. and identity of all particles in every field with an aspect ratio greater than 3:1 and a length greater than 5 μm. For the five filters. a total of 183 particles were characterized in this way. Particles below and above a width of 0.25 μm were noted as well. This width was selected primarily because it is used in references against which the findings of this study shall be compared.[6,7,22,23] These references generally refer to this width as the approximate lower resolution limit of the light microscope.[24] While other references report lower width sensitivity,[25,26] it generally is agreed this lower limit varies with the quality of the microscope, use of dispersion staining and background contrast, magnification, and the microscopist involved. CCSEM with EDX was used on the same carbon-coated filter wedges to scan a total of 2500 particles (500 per sample) at magnifications of 35X, 100X, and 500X. Particles were sized by the preselected parameters. and the chemical composition of all particles was noted. Particle distribution was expressed in volume percent and all tremolite particles were counted. TEM with selected area electron diffraction (SAED) also was employed on new carbon-coated filter wedges from the same five filters. Chemical composition by EDX analysis and SAED patterns of individual fibers which measured 10 μm or greater on four grid squares per wedge were obtained after the filter matrix was dissolved from the carbon film. While considerable data were thus generated from this multiple analytical approach, only data summaries which directly address the definitional comparison are included in this paper.

It should be noted that the EDX chemistries obtained through the CCSEM analysis and the SAED patterns obtained through TEM analysis were not adequate to distinguish talc and anthophyllite. While an in-depth discussion of this problem is beyond the scope of this paper. in summary it should be said that talc may present the same X-ray spectrum as anthophyllite because talc displays a similar 2:1 Si/Mg ratio and overlapping range. Regarding SAED patterns, talc in the fibrous form often reflects the same 5.3 Å spacing as anthophyllite. Talc/anthophyllite in an intermediate or transitional phase poses further identification problems when electron diffraction analysis is restricted to one point per particle. This is more fully described in other papers.[27,28]

Study Results and Definitional Comparison

Table II contrasts bulk tremolite asbestos particles described in the literature[12] to tremolite particles reflected on five New

TABLE II
Ratio Comparison of Bulk Tremolite Asbestos" to N.Y. State Tremolite in Five Air Samples[B] by Optical and Electron Microscopy

Samples	Ratio of Tremolite Particles: 3:1 aspect ratio (a.r.) or Greater to Total Tremolite (>5 μm length) SEM[C]	10:1 a.r. or Greater to Total Tremolite (>5 μm L) SEM	20:1 a.r. or Greater to Total Tremolite (>5 μm L) SEM	10:1 a.r. or Greater to 3:1 a.r. or Greater Opt[D]	SEM
Tremolite asbestos"	1 in 1.6	1 in 2.6	1 in 4.6	1 in 1.6	1 in 1.6
Tremolite asbestos'	1 in 1.8	1 in 2.3	1 in 2.5	1 in 1.6	1 in 1.2
# total tremolite particles per sample (all sizes): 200	(approx. 55%)	(approx. 41%)	(approx. 31%)	1 in 1.5 (66%)	
Tremolite in 5 N.Y. air samples[B]	1 in 6.2	1 in 949 or greater	0 in 949	Opt. 1 in 141 or greater	CCSEM 1 in 152 or greater
# total tremolite particles (all sizes): 949	(16%) CCSEM	(0.1%) CCSEM	(0%) CCSEM	1 in 146 or greater (0.6%)	

"Data from U.S. Dept. of Interior, Bureau of Mines Report of Investigation 8367, page 13. Table 2 (1979)'"'

"Present study CCSEM analysis of 5 air samples at 35X, 100X, and 500X magnifications. (2500 total particle count [all sizes]) Optical (PCM and PLM) analysis of the same 5 samples up to 400X magnifications (534 total particles with a 3:1 a.r. or greater >5 μm length)

[C] Particles counted using SEM with magnification up to 50 000X

"Particles counted using optical-light microscopy at 1250X magnification (200 tremolite particles counted per filter)

'Obtained from California (no other description of literature) Wiley milled

'Obtained from museum sample from Rajasthan India Wiley milled

TABLE III
Average of 22 Mine and Mill Air Samples (2295 Particles) by Compositiun, Aspect Ratio 3:1 or Greater (> 5 μm length), and Mineral Habit by high: Microscopy[A]

Aspect Ratio:	% of Total 31-10:1	% of Total >10:1-20:1	% of Total >20:1	Particles per CC (TWA) 31-10:1	Particles per CC (TWA) >10:1-20:1	Particles per CC (TWA) >20:1	Total Particles per CC (8-hr TWA)	% Asbestiform by Mineralogical Def.
Tremolite	35.8	.33	0	.45	.009	0	0.459	0
Transitional[B]	0.0	.76	0	0.00	.015	0	0.015	0
Talc	58.2	4.60	0	.67	.058	0	0.728	0
All particles	93.0	7.00	0	1.12	0.082	0	1.210	0

[A]Mineral type and % by aspect ratio were obtained by PLM analysis at 100X to 400X magnification. Total particles per cc were obtained by PCM at 400X magnification.
[B]% Talc/anthophyllite transitional particles were extrapolated from 6 of 22 air samples based on a refractive index between 1.592 and 1.608 for the gamma index. No pure anthophyllite particles were noted in the fields analyzed.

York state tremolitic talc air samples by both optical and electron microscopy. In this comparison, the ratio of tremolite particles which satisfy the regulatory definition of a fiber (3:1 or greater aspect ratio, >5 μm length) and those that exceed a 10:1 and 20:1 aspect ratio (>5 μm length) are addressed.

Of the 2500 total particles scanned by CCSEM on 5 air samples, 38% or 949 were tremolite. Of these tremolite particles. 16% or 152 satisfied the regulatory size criteria for a fiber. This represents a ratio of I tremolite regulatory fiber in every 6.2 tremolite particles. In contrast, tremolite asbestos reflected an average of I regulatory size fiber in every 1.7 particles (55%). Most striking, however, is the difference reflected at 10:I and 20:I aspect ratios. For the New York state tremolite, only I tremolite particle in 949 (total counted) exceeded a 10:1 aspect ratio (0.1%). For tremolite asbestos this ratio was approximately 1 in every 2.5 particles or 40%. At a 20:1 aspect ratio or greater, no New York tremolite particles were counted, while 1 in every 3 (approximately) were found for tremolite asbestos. Significant variation in these ratios was not noted under optical microscopy for the same samples at the magnifications applied.

While a bulk to airborne particle comparison is not ideal, the dimensional differences likely would be even greater if two airborne particle distributions were compared, since wider width, lower aspect ratio particles are more common in bulk particle distributions. Published particle distributions for airborne asbestos dust populations support this contention and support the basic dimensional similarity of tremolite asbestos to other asbestiform minerals (see the extended discussion on airborne particle aspect ratio distributions below). Accordingly, on a tremolite to tremolite basis. an entirely different particle-size distribution would be expected in the New York state tremolitic talc samples if this tremolite were asbestiform.

Table III reflects the average of all 22 air samples by percent mineral composition. aspect ratio (3:l or greater), and crystal growth habit (asbestiform or nonasbestiform). Results in this table reflect the combined application of the PCM and PLM methods outlined above.

In the fields analyzed by PLM. no particles exceeded a 20:1 aspect ratio or showed splayed ends. curvature, or parallel fibers occurring in bundles. Using the mineralogical definition, therefore, no asbestos was found; however, 0.459 particles/cc would be noted if the regulatory definition were used (talc and transitional particles excluded). A total of 1.21 particles/cc would be reported if talc and transitional particles were counted. Proper characterization of talc, anthophyllite and transitional particles is extremely difficult in this ore body except by PLM. While PLM air sample data reflect no asbestiform fibers, both talc and transitional particles can appear in a fibrous, asbestiform and/or nonasbestiform habit in this ore body." If misclassified as anthophyllite, these asbestiform fibers would be characterized as asbestos under both the regulatory and mineralogical definitions. TEM SAED analysis with multiple electron diffraction patterns (each indexed) confirmed the presence of both nonasbestiform and asbestiform transitional and fibrous talc particles in a random scan of fields not included in the PLM analysis. No effort to quantify these fibers was made. Because of the rarity of these fibers and their marginal significance to the definitional distinctions being addressed here, further detail in this area is beyond the scope and intent of this paper.

Table IV reflects a comparison of fiber counts obtained in this study with data previously obtained in the same mine and mill (same or similar work activities). These data confirm a marked difference in what is reported as asbestos, depending upon the definition used. Note that the average of all regulatory fibers counted by PCM (Column 2) shows far less variance between investigators than the percent of particles considered asbestiform (Column 5). Mineralogical distinctions made reflect consideration of the characteristics described in the mineralogical definition. Although none of the particles in the study dust population exceeded a 20:1 aspect ratio by light microscopy. this factor alone did not dictate habit characterization for the 22 samples analyzed. Although the lack of 20:1 aspect ratio particles in a dust population certainly suggests a nonasbestiform dust environment, aspect ratios alone are not pivotal in a mineralogical sound definition of asbestos.

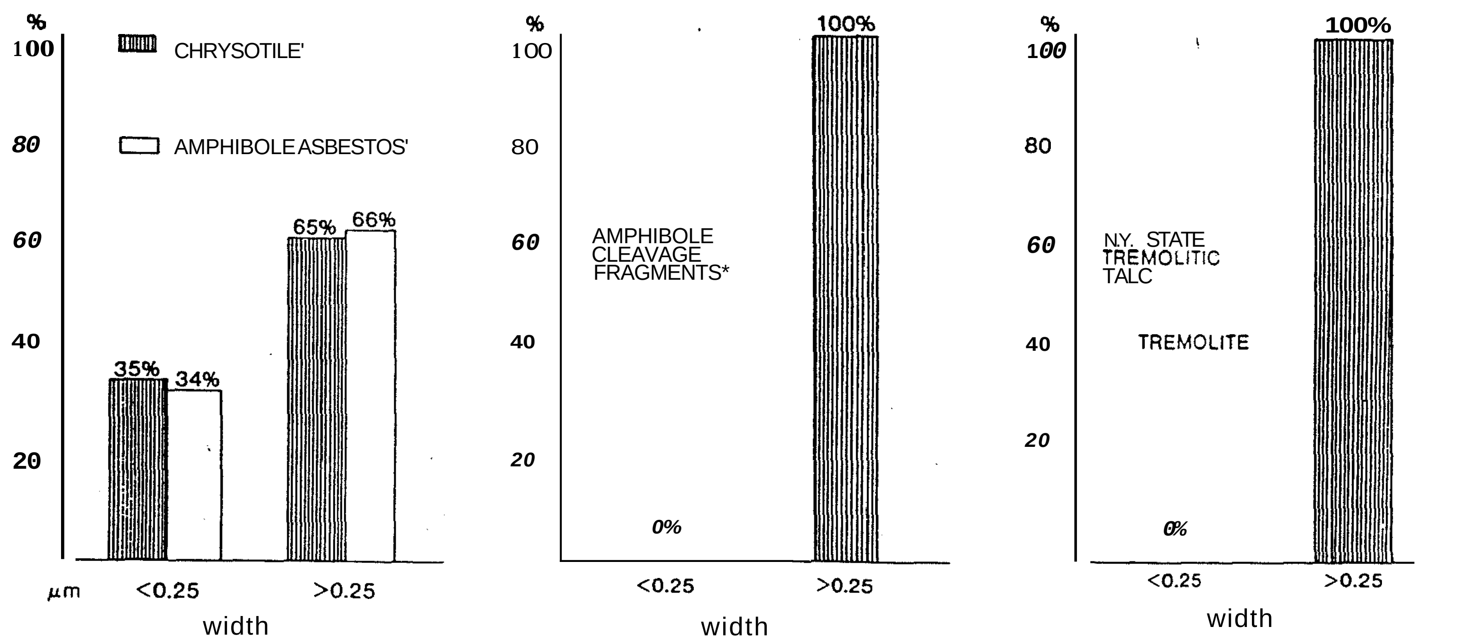
To test definitional specificity further, a comparison of basic dimensional characteristics common to asbestiform dust populations. nonasbestiform (cleavage fragment) amphi-

TABLE IV
Historical Air Samples[A] by Definitional Approach

Source and Year	Average of All Particles/CC Mill and Mine	Range Particles/CC Mill and Mine"'"	Definitional Approach	% Particles/CC Classed as Asbestos	Particles/CC Considered Asbestos
R. Lee (1988)	1.21	0.14–3.56'"'	mineralogical	0.00	0.000
MSHA (1984-85)"	2.39	0.14–18.40[38]	mineralogical	0.40	0.009"
Insurance (1984)[E]	1.8	1.38–2.15[5]	not classed	—	—
NIOSH (1975)'	4.6	1.5–8.4[22]	regulatory	72.00	3.312
Dunn (1982)"	0.65	0.03–1.38[8]	mineralogical but classification completed on bulk samples only	—	—

[A]All particles 3:1 or greater in aspect ratio. > 5 μm in length and resolvable under the light microscope.
"(n) = number of air samples.
'Mine Safety and Health Administration Survey Reports dated: 7/17/85, 7/30/85, 5/22/85, 6/12/84, 1/9/84.
"MSHA performs analysis for fiber type only on filters with elevated total fiber counts. Of the 38 filters, 22 were so analyzed. Of these, 2 filters were reported as containing 2% asbestiform fibers. All other filters were found or assumed to contain 0%.
"Hartford Insurance Company Report dated November 1984 to R.T. Vanderbilt Company, Inc.
'NIOSH Technical Report, Occupational and *Exposure to* Talc Containing *Asbestos.* Table 7 (1980).[21]
[G]Dunn Geoscience Corp. report to R.T. Vanderbilt Company (1985).

bole dust populations, and the study dust population was undertaken. Figure 3 compares airborne asbestiform and nonasbestiforrn particles which fall above and below a width of 0.25 μm, described in the literature,[22] with study dust population particle widths obtained by SEM. With regard to the tremolite found in the talc air samples (the only amphibole noted), all tremolite particles (88 out of 183 total particles) were wider than 0.25 μm. Particle widths noted in



'From: J.G. Snyder. R.L. Virta. and J.M. Segret: "Evaluation of the Phase Contrast Microscopy Method for the Detection of Fibrous and Other Elongation Mineral Particulates by Comparison with a STEM Technique." Am. *Ind. Hyg.* Assoc. *J. 48(5)*:471-477 (1987) Table IV. Average of 17 air samples.

From: Average of 5 air samples analyzed by SEM (represents 88 particles out of 183 total particles).

Figure 3— Average airborne particle width comparison by electron microscopy (all particles 3 1 or greater aspect ratio. 5 μm or more length)

TABLE V
Aspect Ratio **Comparison**

Airborne Asbestos Particles[A] (Mining and Bagging) > 0.25 μm Width, > 5 μm Length					Airborne Cleavage Fragments[B] (Approx. 4500 Total Particles) > 0.25 μm Width, > 5 μm Length				
	% of Particles Seen at:					% of Particles Seen at:			
Aspect Ratio:	3:1	10:1	15:1	> 20:1	Aspect Ratio:	3:1	10:1	15:1	> 20:1
Crocidolite	100	100	91.5	64.5	cummingtonite	100	24	10	6
Amosite	100	100	89.5	58.0	cummingtonite	100	32	7	3
Chrysotile	100	100	86.0	37.0	actinolite	100	15	4	3
Average:	100	100	89	53	grunerite/actinolite	100	8	0	0
					tremolitic talc[C]	100	7	ND[D]	0
					Average:	100	17	5	2.4

[A]Taken from G.W. Gibbs and C.Y. Hwung. Dimensions of Airborne Asbestos Fibers. IARC Scientific Pub. #30 Lyon. France, pp. 79-86.[(23)]

[B]Taken from A.G. Wylie, R.L. Virta. and E. Russek, "Characterizing and Discriminating Airborne Fibers: Implications for the NIOSH Method." American Industrial Hygiene Association Journal. Vol. 46, pp. 197-201.[(7)]

[C]Data taken from the R.J. Lee Group Dust Analysis Project prepared for the R.T. Vanderbilt Co., Inc.. 1988. Reflects PCM/PLM analysis of 22 fillers; % represents 2295 total particles.

[D]ND = not determined.

asbestiform dust populations by STEM differ markedly, with an average of 35% (ranging from 9% to 81%) reported to fall below a 0.25-pm width.[(22)] The similarity between amphibole cleavage fragment particle width and tremolite widths noted in the study dust population, therefore, suggests a nonasbestiform habit. It also might be noted that,, since all tremolite particles exceeded a 0.25-pm width, they should all be resolvable at the lower magnifications used for both PCM and PLM analysis. Further, it is unlikely that particles of this width would be lost in the transfer of particles from the filter to the glass slide in preparation for the PLM analysis.

In terms of aspect ratio, major differences between nonasbestiform amphibole cleavage fragments and asbestiform particles also exist. Table V makes such a comparison for airborne particles which meet or exceed a 3:1 aspect ratio and a greater than 5-μm length. Variances shown in this table typically are found in the literature.[(6,7,23)] Figure 4 graphically depicts these data and further clarifies the difference. In terms of the study dust population, particle aspect ratio distribution is included in Table V under the cleavage fragment column where it best fits. Interestingly, total particulate aspect ratios noted in this study (based on 2295 particles) would represent the low end of the cleavage fragment line in Figure 4. Unfortunately, an airborne dust size characterization for asbestiform tremolite could not be found for inclusion in this comparison. Although asbestiform tremolite is rare and is not exploited for commercial use, localized occurrences do exist in the United States (*i.e.*, California. Montana). At least one industrial hygiene study exists of a mining operation containing asbestiform tremolite, but detailed airborne size characterization is not available.'''' An aspect ratio distribution. however. was obtained on bulk asbestiform tremolite from this mine.'''' For particles longer than 5 μm, 88% fell above 10:1, 70% above 15:1. and 52% above 20:1. These ratios correlate most closely to the average airborne asbestos ratios reflected in Table V and Figure 4 of 100%, 89%, and 53%, respectively.

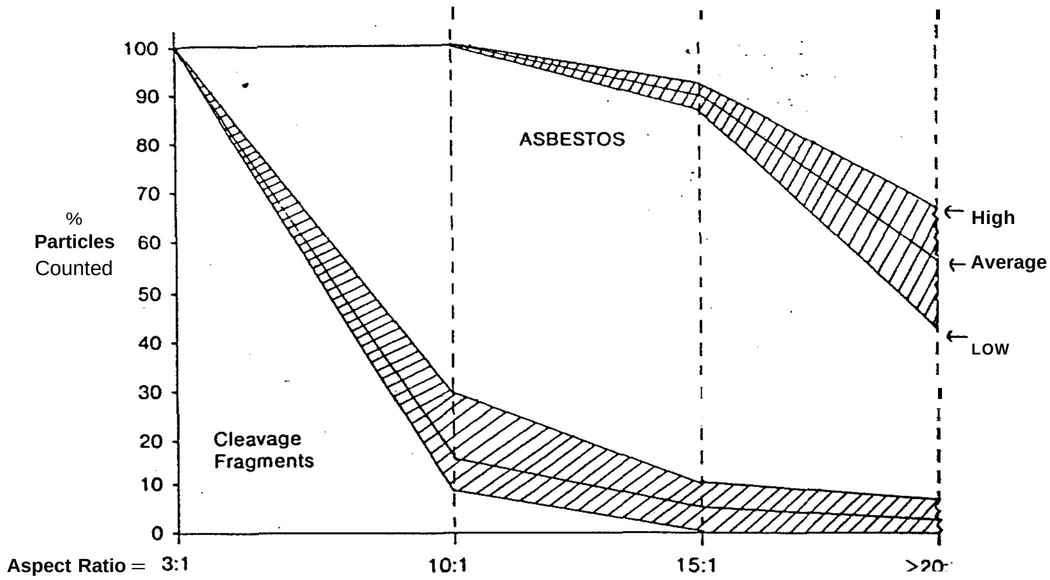
In summary, when the study dust population is contrasted with the mineralogical definition—as well as the dimensional characteristics of asbestiform and nonasbestiform particles reflected in the literature—the nonasbestiform nature of New York state tremolitic talc is quite apparent. The authors believe this reaffirms the nonspecificity of the NIOSH PCM method and the regulatory definitions it underpins when applied to mineral dust environments containing common nonasbestiform cleavage fragments.

Corrective Measures

Given the differences between asbestiform and nonasbestiform particulates, the least dramatic change necessary to improve specificity would involve an upward adjustment in the aspect ratio. As seen in Figure 4, airborne asbestiform particles exceed a 10:1 aspect ratio with very few less than 15:1. Cleavage fragments. in contrast, rarely exceed a 10:1 aspect ratio with fewer still exceeding 15:1. Any aspect ratio adjustment. however. should be applied as a screening tool only because there is some aspect ratio overlap between asbestiform and nonasbestiform particles. It, therefore, is considered essential that a mineralogically correct definition of asbestos and criteria specific to asbestos should be reflected in regulations.

Discussion

Although it is not the intent of this paper to address health issues, the subject cannot be ignored in any discussion regarding the definition of asbestos. It can be argued. for example, that regulatory definitions are designed to address human health concern5 and not the realities of physical science. This argument suffers, however, when it is under-



NOTE: The majority of cleavage fragments do not fall in this range (most reflect lengths of < 5 μm). The 100%. therefore, represents the starting point for 3:1 aspect ratio particle counting and not the total % of airborne cleavage fragments.

Figure 4—Airborne asbestos versus cleavage fragment aspect ratio comparison (particules with an aspect ratio of 3:1 or greater, >5 μm length, >0.25 μm width). From Table V.

stood that health effects attributable to asbestos are not reasonably demonstrated for nonasbestiform exposures.[31-38] Moreover. it can be argued that any environmental exposure ought to be studied and regulated for what it is. To do otherwise presents needless bias.

It also has been argued that any change in the regulatory definition of asbestos would confuse the extensive data base developed for commercially used asbestos. Nonasbestiform amphiboles, however, cannot and are not used for applications typically reserved for asbestos (*e.g.*, insulation, structural binding, fire proofing, brake linings, *etc.*). Accordingly, this asbestos data base would not be affected significantly if a mineralogically correct definition of asbestos were adopted. The definitional ambiguity discussed here relates to dust populations which do contain nonasbestiform mineral cleavage fragments. Such environments commonly involve hard rock and aggregate mining operations and industries who use their mineral products (*e.g.*, ceramics, construction. paint, *etc.*). Whatever asbestos data exist for these environments may be misleading and, therefore. ought to be corrected.

Conclusion

Major differences in crystal growth patterns, lengths. and widths exist between asbestiform particles and common, hard rock-forming mineral cleavage fragments. Current regulatory asbestos definitions and fiber quantification methods do not address these distinctions adequately. Thus. nonasbestiform dust populations can and have been mistaken as asbestiform. Confusion is likely to persist until a regulatory definition and analytical approach specific to asbestos is adopted.

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